## SUMMARY

The remainder of this account will be devoted to the presentation in detail of the analyses, tabulated data, etc., on which were founded the conclusions, interpretations and conjectures so far advanced. Before turning to these technical matters we may summarize what had been accomplished which may be of practical use to Olympia oyster growers.

1) Oystermen now have a graphic and quantitative record of the reproductory performance of their bays during the past 9 years. This record will provide a sort of base-line against which any future improvement or decline may be definitely assessed; and furthermore, since all phases of the reproductive cycle have been treated, the advance or decline can be refered to the specific stages in the life cycle affected.

2) Formulae have been derived for each bay on the basis of which, knowing only the early spring air temperatures recorded at Olympia, one can easily compute and forecast at the end of April in any year and for any bay when spatfall will begin and with an accuracy sufficient to assure maximum, surviving catch of available spat.

3) Similar formulae have been derived by means of which the time of beginning spawning can be predicted about a month in advance thereby permitting the arranging of marketing schedules accordingly.

4) Guidance is provided for predicting on short notice the intensity of spatfall that may be expected from the character of the larvae picture.

5) Quantitative tests show that one must arrange to catch the initial wave of spatfall since the spat caught later in the season has a poorer chance for survival.

6) Two suggestions supplementing each other are offered to explain res in Mud Bay, and a tentative method for foretelling such

failures on the basis of rainfall records and tide tables is presented.

7) Several suggestions have been made for the improvement of cultch and cultching operations.

8) A catalogue of oyster pests is given, including two new enemies not previously described.

## METHODS

In this ~~place~~ section will be described in detail the methods by which the information presented in this paper was gathered. Such procedures can then be repeated at any time in the future when comparable data are desired. We will also give what information we have regarding whether or ~~not~~ to what extent the sampling in any area was typical of the whole bay. Ideally, of course, one would like to have been able to make extensive surveys of spawning, plankton larvae and setting in all bays and then select stations and methods which proved most representative in each bay. But such a study would need to be made during the peak of each of these phases of the reproductive cycle in order to yield large samples of statistical value; and as it happened it was necessary to get some idea and anticipation of the reproductive performance of the bays at once as well as to visit five bays within the short space of one tide once or twice a week. Within these limits therefore we attempted what we could.

### SPAWNING

Since Ostrea lurida is a larviparous oyster, its recent spawning as a female can easily be determined by simply opening the shell and noting the presence of eggs or developing embroys within. One is immediately struck by the presence of thousands of small granules which vary in color from white to gray as they develop shells. Possibly through some early misinterpretation such gravid oysters are called white-sick and gray-sick. That developing, shelled embryos are found shows that fertilization must have taken place and that other individuals must therefore have spawned as males around the same time. O. lurida is protandrous and may spawn both as a male and as a female in one season, though apparently it is not self-fertilizing.

Our spawning data (Tables 4 - 12, Pp. 133-141) therefore represents only the proportion of oysters in the sampled population which have on a certain date recently spawned as females and bear eggs or embryos. We also have distinguished between those which carried young, unshelled embryos (white-sick) and those with shelled (conchiferous, gray-sick) larvae. The only indication we have that distinguishing between the two may be of some usefulness is that low larval abundance and relatively low spatting intensity in North Bay during the season of 1946 was preceeded by the appearance of far lower percentages of gray-sick than white-sick oysters in our samples, much as if the embryos had been aborted or in some way prevented from development to normal, liberated larvae.

For a while we opened 100 oysters from a sample area but it was soon found that the first 50 gave statistically the same values as the 100 and thereafter only 50 were opened ~~thereafter~~ as a sample. Always the oysters were kept in a sack out of water until opened in order that the liberation or possible abortion of embryos would not occur. The sample was always taken from a bed of mature oysters.

Time prevented our sampling more than one area of a bay since we had to sample all 5 bays on one low-tide. Hence we selected what appeared to be a representative dike(designated in the spawning tables) with mature, marketable--not seed--oysters and kept with that local population all season. The spawning data therefore give a valid picture of spawning-as-females of the oysters in a given place in the bays. No attempt was made to compare extent of spawning in several locations in a bay on the same day. We were simply constrained to choose the most accessable dike which was most nearly in the center of the oystering area in each bay. That the sample areas selected were in fact fairly representative of the bays as a whole is indicated by the reasonable correspondence between peaks of larvae abundance (to which spawnings of <u>all</u> areas contribute) and antecedent spawning waves in the areas sampled, including

But unless some further use of the spawning data can be made, its accuracy and representative character is really immaterial anyway since (1) we note, as did Hopkins, that spawning intensity is not appreciably correlated with larvae abundance, the total number of mature oysters in a bay being of far greater relevance, (2) that with the new type of spatfall predictions herein developed spawning information is not necessary, and (3) that there is no important oyster spawning problem in lower Puget Sound. To have determined the latter was of considerable value in itself in directing our attention to other matters.

## PLANKTONIC LARVAE

Hopkins (1937) did not study the abundance of Olympia oyster larvae. Hence he predicted time of setting only on the basis of spawning data. We investigated the larvae for the purpose of short-time predictions of spatting intensity and to learn the extent of larvae production and whether decreases in such could account for poor sets when such occurred. (Tables 13 - 19, Pp. 142 - 148.)

All our plankton samples were quantitative, consisting of the larvae and other plankton forms gathered by pumping or pouring 20 gallons of undisturbed bay water through a net of bolting silk of sufficiently fine mesh to catch the smallest oyster larvae. The catch was then rinsed into a bottle, formalin added and labeled by means of a slip of paper placed within the bottle itself. In the laboratory the bottle was decanted, then agitated and the plankton contents poured out into a counting dish already laid on the stage of a binocular dissecting microscope. Quick dumping of the contents at one side of the rectangular dish resulted in a uniform distribution of the plankton mixture on the bottom of the dish.

This glass bottomed counting dish was marked off symetrically into 64 squares with a diamond point. All the squares crossed by the diagonals of the rectangular dish were subdivided each into three equal parts which facilitated "reading" the count when the larvae were numerous. When the larvae were sdarce, all larvae in all squares were counted; when numerous only those lying within or mostly within the squares on the diagonals were counted and the resulting value multiplied by 4 for the total count; and when tremendously abundant, larvae lying in only one diagonal of squares ~~was~~ were counted and the result multiplied by 8. Comparison of total counts with counts of the 16 squares on the diagonals x 4 gave, for a sample of 42 total count a difference of 5%, for one of 144 a difference of 3% and for one of 1620 a difference of 3%. Hence the shorter method of counting larvae in only the squares on the diagonals of the counting dish was generally used, without significant sacrifice in accuracy.

After counting, the larvae were measured without disturbing the counting dish. This was done with a calibrated occular micrometer or Whipple disc, the occular being rotated when observing each larva to line up the scale with the longest diameter of the larvae shell parallel to the hinge line. Readings were to an accuracy of at least ± 6 microns. The first 100 larvae encountered on a diagonal were measured without selection. Tests on a sample containing 616 larvae showed that if the first 50, the first 80 and the first 100 larvae are measured, the percentage composition of any one size did not differ by more than 3% in each group. A similar test on a sample containing 38,578 larvae measured by groups of 50, 70, 80, 100, 120 and 150 larvae did not differ in percentage composition of any one size by more than 5%. Hence significant error in determinations of size composition of a sample appears only among the very small or the very large larvae since these comprise the smallest size groups.

One is especially interested in the abundance of large, near-setting sized larvae as the most certain indication of the possible set in the near future and of the intensity thereof to be expected. Therefore it is here suggested that larger samples be measured *when it is a question of whether a commercial set will occur or not, as in Mud Bay or South Bay, and when therefore the proportion of large larvae will be very small.*

It follows accordingly that the data we give for percentage of large and near-setting larvae and therefore the abundance of the same are susceptable to considerable error and are to be used as rough indications only. An idea of the variation in proportion of large larvae in comparable plankton samples is gained from noting the values for such given in Table 20 . Since several samples were taken in any one bay on a given date, the *average* percentage of large larvae in all samples was used and these are given in the tabulations of plankton larvae. In this way the error and variation resulting from measuring usually not more than 100 larvae nor less than 50 was in part compensated. In *O. edulis,* Korringa (1940) encountered a uniform proportion of large larvae at any one time in samples taken at different stages of the tide and at the surface and on the bottom.

When we began our work we established stations up and down a bay ~~(Figure 1~~) and sampled them in succession within an hour. It soon appeared however that the extreme stations, down-bay, often yielded relatively few larvae, depending on the stage of tide. This fact at once directed our attention to the necessity for running horizontal sections on a bay during a tidal cycle to follow the movements of the larvae with the current. These studies were done and constitute a quite thorough investigation of the variation between plankton samples at different locations in a bay on the same day. They are described in detail in another section ( P. 73 ).

## TABLE 20: PLANKTON LARVAE FIELD DATA, OYSTER BAY, 1949

| DATE | TOTAL COUNT* | NO. LARGE LARVAE** | PER CENT LARGE LARVAE |
|---|---|---|---|
| May 27 | 16 | | |
| | 8 | | |
| June 2 | 416 | | |
| 8 | 8032 | | |
| | 7104 | | |
| | 7584 | | |
| 13 | 12,928 | | |
| | 5,064 | | |
| | 11,440 | | |
| 16 | 16,256 | | |
| | 6,256 | | |
| 20 | 1,992 | | |
| | 1,264 | | |
| | 3,096 | | |
| 23 | 8,112 | | |
| | 8,736 | | |
| 26 | 9,074 | 752 | 8 |
| | 10,864 | 1,264 | 12 |
| | 7,072 | 480 | 7 |
| 30 | 568 | 120 | 21 |
| | 142 | 24 | 17 |
| | 3,976 | 704 | 18 |
| July 5 | 13,536 | 208 | 2 |
| | 8,456 | 408 | 5 |
| 8 | 2,288 | 128 | 6 |
| | 11,856 | 528 | 4 |
| 11 | 8,640 | 144 | 2 |
| | 5,360 | 16 | 0 |
| | 2,112 | 64 | 3 |
| 18 | 960 | 664 | 69 |
| | 6,960 | 480 | 7 |
| 21 | 2,088 | 400 | 19 |
| | 1,480 | 480 | 32 |
| | 1,360 | 328 | 24 |
| 27 | 2,632 | 416 | 16 |
| | 1,672 | 312 | 19 |
| | 856 | 112 | 13 |

* Total number of plankton larvae per 20 gallon sample

**Described as "advanced ~~Umbo~~ umbo to setting size".

Plankton sampling (larvae) and dike stations (spawning and setting) for all bays are located in Figures .

We now come to the question of how well repeat samples taken at the same location or depth in rapid succession agree with each other. In Table 21 are given the results of the tests made. The larvae counts given are of course to be compared strictly within one station on one day; apparent discrepancies between the data of successive days at a given station are due to favorable or unfavorable tidal conditions obtaining at the time. General agreement as well as considerable variation will be noted in comparing the duplicate samples, a point which we shall return to in a moment.

Comparisons also were made between samples taken at designated stations and others taken immediately following at a distance of a few hundred yards away. The results are summarized in Table 23, P. 152. Again general agreement but considerable variation will be noted and will receive comment later.

During 1945 we established extra stations ("A" series) at approximately the same distance up the bay as our regular stations but on the opposite side of the bay. The pairs of stations were sampled in close succession with no greater time interval than was necessary to move from one to the other. Table 23 presents the comparative larva counts for paired stations on the same day. The variation in this series is great and therefore very disturbing. Some of it may be accounted for by the fact that the "A" stations were near or over oyster dikes rather than in channels like the partner stations and hence may have shown swarms of larvae just liberated by the oysters locally. In any case high counts were not consistently found for one station but first one and then the other station would show higher numbers of larvae per 20 gallon sample.

In 1945 a series of comparative plankton samples at different depths were taken in order to gain some notion of the vertical distribution of the larvae. It will be seen from Table 24/ P. 153 that no consistent rule of distribution obtains. It also appears that one may miss the bulk of the larvae by sampling at the wrong depth. There is not much one can do about this possibility of error since depth samples with pump and hose are most time-consuming. (Korringa, 1940, found no significant difference in abundance of O. edulis larvae at surface and at the bottom.)

For a small number of samples the water was obtained by dropping a length of garden hose over the side of the boat, sucking up the water with an impeller bilge pump and allowing it to run through a plankton net into a 20 gallon barrel until the barrel was filled. Pump samples gave slightly higher larvae counts than duplicate bucketed samples (see Table 25 P./154). No crushed shells of larvae were found. Hence a pump arrangement is satisfactory for sampling oyster larvae.

We also compared the catch with pumped samples when the boat was moving slowly and when it was stationary. As shown in Table 25 , the samples are quite comparable; hence the boat need not be at rest when samples are taken with hose and pump. (Cf. also Korringa, 1940, p. 40.)

The degree of variation we find in plankton samples taken in a bay at the time when and the locations where maximum larvae may be expected is shown in the data of 1948 as follows:

## TABLE 22: LARVAE COUNTS OF INDIVIDUAL PLANKTON SAMPLES TAKEN DURING 1948

| DATE | OYSTER BAY | MUD BAY | NORTH BAY | SOUTH BAY |
|---|---|---|---|---|
| June 15 | 1124 | | 160 | |
| | | | 620 | |
| 22 | 1827 | 112 | 3216 | 148 |
| | 3824 | 1224 | 648 | 96 |
| 28 | 2088 | 2020 | 64 | 112 |
| | 728 | 4912 | 112 | 112 |
| July 1 | 1160 | 804 | 4264 | 724 |
| | 6320 | 736 | 1608 | 60 |
| | 3264 | | 512 | |
| 5 | 12,224 | 6144 | 5440 | 1112 |
| | 3,872 | 6116 | 3432 | 1168 |
| | 12,000 | | | |
| 12 | | 92 | | 32 |
| | | 120 | | 40 |
| | | 192 | | 20 |
| 15 | | 144 | | 168 |
| | | 336 | | 328 |
| | | 2424 | | 12 |
| 19 | 2472 | 3200 | | 524 |
| | | 5200 | | 376 |
| | | | | 832 |

In regard to the above one could certainly wish for closer agreement in the samples and yet they are sufficient to the problem of determining the relative larvae productivity of the bays and whether abundance is adequate to provide the basis of a satisfactory set in each bay.

Now we may ask, what kind of picture of oyster larvae distribution in our bays do these tests imply in the aggregate? They suggest a Larvae Mass which moves back and forth in the bay with the tide and which is itself quite "spotty" with regard to density of larvae at any one locus within the mass. We may picture it as follows, having in mind that the "spottiness" is found in the vertical as well as in the horizontal distribution.

(INSERT
(Picture Fig. 44 )

There is little doubt that extensive study would reveal more order in distribution both horizontally and in depth in relation to tidal velocities, occurences of channels, etc., but such an investigation is not justified in view of the fact that the situations we have to deal with is simply whether a set is going to be a success or a complete commercial failure not profitable to cultch. Only if we were confronted continually with "borderline cases" wherein the set was year after year on the edge of being worth or not worth the cultching would it be necessary to determine the abundance of larvae with high accuracy. Practically we therefore use our knowledge from the tidal cycle studies of movements of the Larvae Mass to locate approximately the center of the mass in a bay at the stage of tide obtaining at the time of our visit and then cruise about in this general area, taking several samples, trusting that we shall hit one or more "spots" of relatively dense larvae in the surface water. Samples are taken at a depth of about 12 inches to avoid surface debris and possible effects of surface rainwater and of wave adtion. (Korringa (1940) finds that *O. edulis* larvae do not drop out of the surface layer of the water either in rough weather or in calm).

The maximum count in a set of samples is used as representative of the abundance of plankton in the Larvae Mass. It must be explained why this and not the *average* count is given in the tables and presented in the graphs. There are three reasons. The first is that we must postulate that the larvae abundance is in fact not very "jumpy" but waxes and wanes in rather smooth continuity throughout the season; and the maximum counts approximate ~~yield~~ such a theoretical curve better than do the average counts. Hence we have concluded that the maximum counts more nearly represent the true picture than an invalid average of only a few samples. The second reason is that a given piece of cultch receives the setting oysters from a *moving* body of water and therefore if properly located will draw on the maximum density available. For although we do not know what precicely happens when *Ostrea lurida* larvae begin to set (a worthwhile study could be done on near-setting larvae gathered in the field and "set" in the laboratory), we may suppose from the observations of Prytherch on *O. virginica* (1934) that the situation is not like a game of musical chairs in which at a given signal, a larva has to set on anything available. Instead Prytherch finds that the larva seeks and tests the available substratum and if it does not find proper cultch may take off and swim again several times before it finally achieves attachment. Eventually of course the larva will have to set even on mud with consequent suffocation but we think it reasonable to guess that it has some time in which to test out the possibilities.

The larvae curves in the bay-year graphs therefore show maximum counts per 20 gallons obtainable by our methods of sampling. In ~~not~~ only six ~~more than three~~ cases throughout all these graphs were data omitted as being completely out of line with the trend of larvae abundance. It was considered reasonable to discount such ~~obvious discrepancies and if this~~ anomalous low values (indicated by parentheses in the Tables of larvae abundance) since obviously larvae cannot have nearly ~~judgment be questioned, then one is welcome to make his own graphs from~~ disappeared from the bay on one day and reappear close to their prevailing ~~the data of the tables, which are complete.~~ abundance a few days later.

We shall not leave this topic without assessing the merits of increasing the accuracy of larvae counts and determination of the larger size groups thereof. It has already been remarked that the spawning samples are now rendered unnecessary because (1) there is no "spawning problem" that could not be solved by increased plantings of spawning stock (as should be done in South Bay, for instance) and (2) time of beginning spatfall can now be determined from the early spring Thermal Trend without reference to time of spawning. The new prediction method presented in this publication also makes it unnecessary to take series of plankton samples in Oyster Bay and North Bays as long as these bays regularly produce a commercial set anyway. Hence one may advise that the time saved be used in <u>intensive</u> larvae surveys when and only when it is a question whether the cultching will be worth the cost or not, as in Mud Bay, and South Bay in certain years. In addition, one plankton sampling in each of the bays a week before the date of predicted beginning set will check the forecast and should make possible an even closer determination of the date for optimal cultching.

If the planktonic larvae samples had been more accurate and less variable----which was impossible to achieve in the time available---- undoubtedly such "jumpiness" as appears in the bay-year graphs would have been largely smoothed out. But this is now water under the bridge.

Let it be noted however, that the abundance of the data gathered itself made possible the simplification in procedures later realized; and furthermore that studies of magnitude of spawning, larvae growth and abundance, and setting intensity establish norms which will permit the location of possible future difficulties, as they have pointed to failure of the larva to survive to setting size as the biological cause of certain spatting failures in Mud Bay. Gaining a definite picture, if not always as precise as could be desired, of the quantitative aspects of the stages in the reproductive cycle in the various bays and the normal variation thereof thus represents an indubitable value, however easily overlooked.

## SETTING

An adequate treatment of spatfall requires a quantitative determination of spatting rates at frequent periods throughout the setting season as well as of the over-all effective, surviving catch which will contribute to the perpetuation of a stock of oysters on the beds. (Tables 26-39, Pp. 155-168.)

After 1943 glass plates in weighted holders and chicken-wire bags of Pacific oyster shells were not used. Bags of shell are clumsy to handle, they silt in on the bottom and, since the shells lie at random angles as well as exposed or buried within the bag, the catch per shell is extremely variable and large numbers of shell must be examined for reliable results. If used for seasonal cultch they remain in the bay long enough for disintegration of the wire to occur. Glass plates can be held in the horizontal position for optimum setting but we found that such smooth surfaces catch one half or less spat then cemented cardboard or oyster shells and are difficult and clumsy to"read" for spat-counts.

The test cultch settled on consisted of strings of a dozen market-sized, flat, upper valve or "top" shells of the Pacific oyster, Ostrea gigas. Only clean shells of as uniform size as could be selected on sight (average of 11.6 square inches each in a sample of 100 measured) were punched in the center and strung on heavy galvanized wire with the inner faces of the shells facing downward. The shell-strings were then suspended from frames placed in the oyster dikes so that the shells were horizontal and always covered with water at low tide. Shell strings were taken to and removed from the shell racks at regular intervals throughout the summer and each week during the setting season a fresh string was labeled and hung on a rack to remain until the end of the season. Two overlapping series of weekly strings removed in alternation biweekly were used during some years.

When the test cultch strings were removed from the bay they were hooked on a carrier rack in such a way as to keep the shells from jostling against each other and scrapping off spat. At the laboratory the shells, now dry, were examined one by one on the smooth under surface only and the spat counted under a binocular dissecting microscope. A microscope is essential for distinguishing between mussel or barnacle or bryozoa set and oyster spat. With good illumination the bright, white, inner surface of the shell results in even the smallest spat standing out in an altogether satisfactory manner and one can therefore determine spatfall rates promptly without having to wait and grow the spat to larger size as is necessary with the cemented glass plate test cultch used in Holland. When the spatting was heavy, guide lines were drawn on the shells to facilitate counting the spat.

Two strings of 12 cultch shells each were put out together as "weekly strings" in each bay. Usually all 24 shells were examined and the average spat per shell determined. The number of days the shell was in the water was also considered in calculating the average number of spat per 100 shell~~s~~ faces per day which we call the Setting Index, a measure of the rate of spatfall so formulated as to exclude "unintuitable" decimals.

The cultch string pairs therefore constituted duplicate samples, and that they agreed very closely is a sign of the reliability of the method. Thus in Oyster Bay during 1944, for example, duplicate samples, gave the following values for successive periods throughout the setting season.

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 176 | 1023 | 838 | 1961 | 978 | 2107 | 556 | 527 | 378 | 622 | 238 | 1795 | 50 | 37 | 7 | 9 | 5 |
| 2 | 195 | 815 | 704 | 1326 | 764 | 2570 | 497 | 552 | 350 | 661 | 137 | 1322 | 59 | 37 | 9 | 6 | 4 |

The uniformity of results shown amply answers the ~~possible~~ objection that shell-strings are altogether unsatisfactory because of their irregularity in size and shape.

Since there was time on a given low tide to visit only one cultching station in each of the bays, the question arises whether the spatting at the site chosen was typical of the whole bay. We located our test cultch racks as closely as possible to the center of the area in each bay which is cultched commercially, and arranged that they were not placed near dike walls, spillways or other atypical locations. The same dike stations were kept from year to year with insignificant alteration of position.

In Oyster Bay the test cultch was on the East side of Dike 5 of the Olympia Oyster Company. During the 1946 season four additional dikes at Burns Point (see Fig. 1 ) were cultched. Setting data at these five different locations is compared in Table 40 .

(INSERT Table 40) (P. 66)

The agreement between these five stations is greater than one would have perhaps expected although it is to be noted that Dike 5 and Burns Point are about the same distance up-bay. Nevertheless this is the heart of the cultching area and Burns Point is adjacent to the sink in which floating cultch is moored. It is therefore indicated that the setting data is representative of the bay and that it is the most accurate

TABLE 40: ~~Seasonal~~ Setting Indices during 1946 at four Burns Point dike stations in Oyster Bay compared with Dike 5 station

Setting Index at Mid-dates

| Burns Point Dike | June 29 | July 6 | July 12 -13 | July 19 -20 | July 27 | Aug. 4 | Aug. 11 -12 | Aug. 17 -18 | Aug. 24 -25 | Sep. 4 -5 |
|---|---|---|---|---|---|---|---|---|---|---|
| No. 1 | 620 | 1718 | 703 | 263 | 107 | 529 | 1750 | 1440 | 245 | 181 |
| No. 2 | 1164 | 4004 | 1718 | 398 | 206 | 637 | 1955 | 2745 | 620 | 454 |
| No. 3 | 1070 | 2202 | 1092 | 399 | 166 | 602 | 2098 | 1507 | 616 | 147 |
| No. 4 | 813 | 3575 | 1027 | 686 | 221 | 522 | 1643 | 1918 | 836 | 204 |
| Average of all 4 | 917 | 2875 | 1135 | 436 | 176 | 572 | 1861 | 1901 | 580 | 246 |
| Comparable setting at Dike 5 | 800 | 2700 | 600 | 200 | 150 | 400 | 1000 | 2000 | 800 | -- |

of all our groups of data.

Seasonal strings were taken up in the fall and spat counted on both sides of the shells. One could therefore tell how much set accumulated on cultch put into the bay on or near the date the test string itself was set out. The spat were measured and the larger spat from the first peak of spatfall usually separated from the small spat from secondary waves of spatting. A large proportion of the latter were invariably found to be dead and only the large spat are tabulated in the tables of seasonal cultch as being the effective, surviving catch of the season (see P. 87). (Tables 41-46, Pp. 169-174.)

## LARVAE SIZE AND ABUNDANCE

It is of course quite simple and possibly instructive to determine the size distribution of Olympia oyster larvae obtained in the plankton samples. In this connection one wants to find the answers to several questions:

1) Is the larva Mass well-mixed as to size groups, or do certain regions and samples show different proportions of sizes?

2) Is there a stratification of larvae sizes such that, possibly, the larger and presumably heavier larvae tend to layer in a deeper level of the water?

3) Are there definite modes in the range of sizes, and can such sige groups be followed through to setting?

4) To what extent can intensity of spatfall be forecast from abundance of growing plankton larvae?

These questions will now be considered to the extent of our *present* information.

## 1)HORIZONTAL DISTRIBUTION OF LARVAE SIZE GROUPS

One would like to know whether a plankton sample at one-foot depth taken anywhere in the bay on the same day will yield the same proportions of size groups. Again there was not sufficient time for a thorough survey of the problem and we had to compromise on a quick review of certain samples for the practical purpose of testing whether our assumption of uniformity in distribution was entirely erroneous. The samples from a horizontal section of Oyster Bay during a cycle of tides on 8 August 1944 accordingly were looked over by the staff member who customarily measured the oyster larvae in our routine. Of a total of 33 samples, 20 were designated as having a "high" percentage of large larvae, 2 as having a "good percentage", 2 with a "fair" percentage, one as having "very few" large larvae, and 8 were at the periphery of the Larvae Mass and so contained too few total larvae for significant comment regarding size distribution. Hence 80% of the samples which contained considerable numbers of larvae up to 640 per 20 gallons showed an obviously high percentage of mature larvae and 88% were reported as being "high" or "good" percentage of large forms. We therefore conclude that the mixing effect of daily tidal currents is accomplished and that variations in size distribution of larvae from place to place in the bay is a minor consideration.

## 2) DISTRIBUTION IN DEPTH OF LARVAE SIZE GROUPS

Since studies of the size distributions of larvae with reference to depth of water should be done when the reproductive season is in full swing and there are abundant oyster larvae, we have been unable yet to make adequate investigations on this point because at such a favorable time we have always been too occupied with following the set in addition to sampling the plankton. We shall however report what indications we have even though they are not conclusive, having in mind that they may give us probabilities if not certainties and guide the course of further studies.

On September 5th, 1944, at the end of the season when final traces of larvae in the water were spatting out in the last surge of spatfall, a minor study of size distribution in relation to depth of water was made in Oyster Bay. Water samples were obtained by hose and pump and filtered through a plankton net in the customary manner. This was done at about two hours after low water on a 11.2 foot tide, therefore when the larvae were subjected to considerable flooding tide current. The information obtained was as follows:

(INSERT Table 47)

## TABLE 47: SIZE DISTRIBUTION IN RELATION TO DEPTH OF SAMPLE, OYSTER BAY, September 5, 1944

| Diameter of larvae in microns | STATION 8 | | | STATION 9 | | | | |
|---|---|---|---|---|---|---|---|---|
| | 0 ft. | 3 ft. | 6 ft. | 0 ft. | 2 ft. | 3 ft. | 6 ft. | 11 ft.* |
| "small" | | | | | | | | |
| 168 | | | 4 | | | | | |
| 192 | | 20 | | | | | | |
| 204 | | 12 | 12 | 45** | | | 34** | |
| 216 | | | 4 | | | | | |
| 228 | | | 8 | | | | | |
| 240 | | | 20 | | | | | |
| "large" | | | | | | | | |
| 252 | | | | | | 24 | 34** | 24** |
| 264 | 8 | | 8 | 4** | | 12 | | |
| 288 | | | 8 | | | | | |
| 312 | | | 4 | | | | | |
| Total larvae per 20 gallons | 8 | 32 | 68 | 8 | 0 | 36 | 68 | 24 |

* One foot off bottom.

** In th~~ree~~ese samples the larvae were simply grouped as under or over 240 microns in diameter.

These data when coupled with the facts (1) that we do find large larvae up to setting size in our usual 1-foot plankton samples and (2) that we find good set on floating cultch, show at least that there is no exclusive stratification of larvae sizes. We have therefore acted on the probability that the different size groups of larvae are relatively evenly distributed where they occur.

### 3) THE POSSIBILITY OF FOLLOWING LARVAE GROUPS THROUGH THEIR PELAGIC LIFE TO SETTING.

On this subject all that needs to be said is that since the spawning period of the Olympia oyster is usually so protracted, larvae of all sizes are found in the plankton throughout the season except at the beginning and at the end. Hence one cannot ~~clearly~~ easily follow the outcome of a single spawning as is possible with the Japanese oyster and *Ostrea virginica* which have sharp spawning peaks. The extent to which one can is indicated in Figures 66-70.

### 4) RELATIONSHIP OF ABUNDANCE OF LARVAE IN GENERAL AND OF LARGE LARVAE IN PARTICULAR TO INTENSITY OF SPATFALL.

The graphs of the bay-years herein presented show the curves of the abundance of large larvae and of total larvae per 20 gallon sample of bay water. This is the data we have to go on in predicting intensity of actual setting which is also shown in these graphs. (The excessive proportions of large larvae recorded for 1949, and 1950 may be regarded with some scepticism as possibly a trend in the observer to include smaller and smaller larvae in his "advanced umbo and near-setting size" group.)

Abundance of total larvae and therefore also of large larvae is of course correlated with the number of spawning oysters in a bay. Thus Oyster Bay has the most extensive beds and the greatest abundance of larvae, and Mud Bay, North Bay and South Bay follow in that order. South Bay apparently does not produce enough larvae for a gratifying set. (We omit consideration of Oakland Bay because of the ~~obvious~~ abnormal circumstances in this industrial area). Correspondingly, Oyster Bay leads with the highest average intensity of spatfall. North Bay can however apparently produce surprisingly high Setting Index maxima with a relatively low concentration of larvae (vide 1945 and 1948). Very roughly speaking, in all the other bays the area under the first setting curve is equal to the area under the first curve of larvae abundance, as plotted on the coordinates chosen in the bay-year graphs. This is indeed approximate, but allows one to get some idea of the extent of spatfall to be expected before it occurs. A further point is that larvae which have attained three-fourths of their growth or more toward setting size must reach an abundance of about 100 (or greater) per 20 gallons before substantial setting can begin. The greater the abundance of large larvae above this figure the heavier the set.

## DISTRIBUTION OF LARVAE DURING A TIDE

In order to obtain accurate and representative plankton samples it is necessary to know the effect of the movement of the tides on distribution of the pelagic larvae. To this end a number of surveys were made in which one either sampled in one spot continuously, cruised rapidly up and down the bay taking samples during a run of tides; or stationed a man sampling from a boat at each of several locations throughout the length of the bay. The results proved very interesting from several standpoints as previously noted (P. 29 ) and will now be discussed in detail.

1) <u>Tidal Cycle Plankton Study of Oyster Bay, Station No. 9, Aug. 8, 1944</u>.

On this date our boat was anchored at Station 9 for 13 hours and plankton samples taken at 1 foot depth every 30 minutes. In addition a few samples were taken by skiff at Station 8. All samples were 20 gallons in volume. The field data is given in Table 48 of the Appendix (P.175 ).

The findings are summarized graphically in Figure 45 . The Oyster larvae curve was smoothed by a moving average of threes. Height of the tide throughout the period is calculated as for Burns Point, which is just across the bay from Station 9. In addition, a curve of tidal current velocities is supplied. This was calculated from U. S. Coast & Geodetic Survey Tide Tables as for Dofflemyer Point at the mouth of Budd Inlet. As such they are only suggestive and do not ~~necessarily~~ represent the actual current velocities at the time up in Oyster Bay, but they are the only data of this type which we have available.

The wide range in plankton larvae abundance possible at this one station throughout a tide is apparent, individual samples ranging from 4 to 772 larvae per 20 gallons.

On the basis of this one study it could not be decided with certainty whether the larvae move up and down the bay or merely come to the surface layer sampled, due to some action of tidal current; for the peaks of abundance at Station 9 correspond both to mid-tide stages and to maxima in current velocity. But since oyster larvae are purely pelagic it is reasonable to suppose that they move up and down the bay with the tide. A further point is that if tidal currents merely brought them to the surface, then the greater current velocity at ebbing should be expected to yield the greater larvae abundance, yet the peak at maximum flooding is far higher. We need not speculate however because further surveys to be described amply demonstrate that the Larvae Mass moves up and down the bay with the tide.

Starting at early morning high tide, then, the Larvae Mass is up-bay from Station 9 (Fig. ~~4~~ 47 ). As the tide ebbs it comes past the station in an initial wave of larvae abundance. At low tide the mass is down-bay. As flood begins the mass then moves back to Station 9 and then beyond.

From this study it is clear that at Station 9 in Oyster Bay the samples should be taken at about 3 1/2 hours before high tide to give a measure of the maximum density of the Larvae Mass.

We now have to explain why, as the Mass moves *down* the bay past Station 9 at ebbing, its density is less than when it returns *up* the bay on the flood. A certain observation may here be relevant, namely, that when *Ostrea lurida* larvae are kept in an aquarium in the laboratory with no current they invariably collect and remain near the surface. Hence they appear to be negatively geotropic, always tending to swim upwards in the water and to keep themselves at the surface by continuous action of the velar cilia. If this is true in the natural habitat, then our Larvae Mass may be viewed as generally tending to lie ~~on~~ at or near the surface of the bay.

Aggitation of the water by tidal currents would result in the mixing

mixing of the surface water with deeper layers, with high current velocities at such a rate that the larvae had not time or were powerless to come to the surface. The hypothesis is therefore offered that the reason the larvae abundance is less at mid-ebb than at mid-flood is that at the former stage of the tide the current velocity with its churning and mixing action is greatest and drives part of the larvae out of the surface layer. The reason the tide current is greater on ebbing than on flooding is of course that the run-out of water confines it more to the center-line of the bay and hence has the same effect as a constriction in a pipe.

It follows that to obtain a measure of the maximum density of the Larvae Mass samples should not only be taken at the time mentioned but also in an area near Station 9 away from channels and having the minimum velocity obtainable at mid-flood tide.

2) Study of Oyster Bay, Station No. 9A July 9, 1945

Station 9A is off Burns Point. The data obtained in the surveys are tabulated in Table 49 P. 176 , and graphically set forth in Figure 46 .

(INSERT Fig. 46.)

The larvae curve again shows a general rise around mid-flood tide. Differences from the cycle previously described are (1) that a residue of larvae are still found at slack low tide and (2) that the peak of maximum abundance is bimodal. Thus within a half hour, from 5:30 to 6:00 PM we obtained a range of 4000 to 6400 larvae.

Now from the contour of the bay at Burns Point as well as from the observation of oystermen we may say that it is probable that there is a back-eddy or "whirlpool" at station 9A which could account for the differences from the results at Station 9 across the bay (see also Table 23 , P. 152 ).

We conclude first, that the general picture of the movement of a Larvae Mass back and forth past an up-bay sampling station is confirmed, and second, that other factors, presumably of the nature of back-eddies make Station 9A somewhat unsatisfactory for sampling as compared with Our regular Station 9.

### 3) Horizontal Section Down Oyster Bay, July 24, 1945.

On this date we took our boat up and down the bay at a time from mid-ebb to low tide, sampling at the stations designated in Fig. 47 .

(INSERT Fig. 47)